Available online at www.sciencedirect.com

SCIENCE DIRECT®

Nuclear Instruments and Methods in Physics Research A 522 (2004) 56–61

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

www.elsevier.com/locate/nima

TEC/TRD for the PHENIX experiment

K.N. Barish[a], S. Botelho[b], W.C. Chang[c], O. Dietzsch[b], A. Franz[d], S.Y. Fung[a], L. Kotchenda[e], D. Kotchetkov[a], P. Kravtsov[e], A. Lebedev[f], X.H. Li[a,*], J. Mahon[d], S. Mioduszewski[d], M. Muniruzzaman[a], B. Nandi[a], E. O'Brien[d], R.P. Pisani[d], M. Rosati[f], R. Seto[a], C.L. Silva[b], E.M. Takagui[b], W. Xie[a], X. Zong[f]

[a] *University of California - Riverside, Riverside, CA 92521, USA*
[b] *Universidade de São Paulo, São Paulo, Brazil*
[c] *Academia Sinica, Taipei 11529, Taiwan*
[d] *Brookhaven National Laboratory, Upton, NY 11973, USA*
[e] *PNPI,Petersburg Nuclear Physics Institute, Gatchina, Russia*
[f] *Iowa State University, Ames, IA 50011, USA*

Abstract

The TEC/TRD is a set of large multi-wire tracking chambers in the PHENIX experiment with fiber radiators in front of the tracking volume. It provides charged-particle pattern recognition, momentum measurement and particle identification through determinations of both ionization energy loss (dE/dx) and associated transition radiation (TR) photons. A custom front-end electronics is instrumented with a dual-gain system to read out the dE/dx and the TR events. A recirculating gas system for the Xe-based mixture is developed. The device will be fully operational starting in December 2003. It will provide e/π separation with momenta ranging from 0.25 to 50 GeV/c.

PACS: 29.40.−n; 29.40.Cs

Keywords: Multi-wire chambers; Ionization loss; Transition radiation; Xenon recovery system

1. Overview

The Time Expansion Chamber/Transition Radiation Detector (TEC/TRD) is a large system of tracking detectors in the PHENIX experiment at RHIC [1]. It is located in the east central spectrometer arm and composed of 24 large multi-wire chambers arranged in 4, 6-plane sectors [2].

The TEC/TRD tracks all charged particles passing through its active area, providing a number of functions for the experiment. It computes direction vectors that are matched to track information from the Drift Chamber (DC) and Pad Chambers (PCs). With the position resolution of less than 380 μm, the TEC/TRD enhances rejection of background tracks not originated from the beam interaction point. It improves momentum resolution of the east central spectrometer at $p_t > 4$ GeV/c combining with the DC to provide a long track lever arm. Simulation

*Corresponding author.
E-mail address: lixh@rcf2.rhic.bnl.gov (X.H. Li).

0168-9002/$ - see front matter
doi:10.1016/j.nima.2004.01.018

shows, for particles with momentum of 40 GeV/c, that $\Delta p_t/p_t$ is 18% by using only the DC information, and 4% by using both the DC and the TEC/TRD informations. The TEC/TRD measures ionization energy loss ($\mathrm{d}E/\mathrm{d}x$) of charged particles and transition radiation (TR) energy of electrons. It allows e/π separation over momentum range of 0.25–50 GeV/c [3]. Since secondary particles are increased in p_t reconstruction with only the DC information (*increased*/*originated* $\propto R^2$, where R is the radial distance of the original point to the beam line), and CO_2 gas used in the Ring Imaging Cherenkov (RICH) has a pion Cherenkov threshold of 4.65 GeV/c [4], the TEC/TRD enhances the high p_t physics program at the experiment. It facilitates measurement of anti-quark helicity distribution through W production in polarized p+p collisions and through W decay into e and ν_e.

2. Detector design

Each TEC/TRD plane is built in two layers [2]. The lower layer contains structural elements for window support and a radiator sandwich. The upper layer contains active elements of the wire chamber including a Cu-mylar cathode window, 3 cm drift space, three wire planes (cathode, anode, cathode), and a Cu-mylar cathode back bias window.

A radiator sandwich is composed of 10 sheets of 17 μm polypropylene fibers (LRP 375 BK 600) on top of a Rohacell (IG 51) shell and a fiber cushion. Each fiber sheet is 0.5 cm thick with a density of 60 mg/cm^2. The shell, with a thickness of 0.636 cm and the density of 52 mg/cm^2, provides mechanical stability. All except the cushion are wrapped in mylar foil. A sandwich is 151–174 cm in length, 25 cm in width and has 0.94% X_0 of material.

Each anode wire is read through a preamplifier/shaping amplifier and digitized to determine the time profile and the pulse height of the signal [5]. A dual gain system is developed to be simultaneously sensitive to both the $\mathrm{d}E/\mathrm{d}x$ and the TR events. The signal is split after the shaping amplifier and two outputs are provided with nominal gain of 25 and 5 mV/fC for the $\mathrm{d}E/\mathrm{d}x$ and the TR measurements, respectively. After amplification, the pulses are sent to a nonlinear flash analog-digital converter (FADC) which digitizes both the $\mathrm{d}E/\mathrm{d}x$ and the TR signals at 40 MHz and encodes the result into a 5-bit output with a 9-bit dynamic range.

3. TEC/TRD operation and performance

Charged particles passing through the chamber ionize the gas, and resulting electron clusters drift in the radial direction into the amplification region, where the signal is collected by the anode wires (Fig. 1). The FADC readout provides 80 samples in a 2 μs window. Each time sample provides position measurements in $r-\phi$ and a $\mathrm{d}E/\mathrm{d}x$ measurement. Position measurements are translated into direction vectors for each track to be used in both pattern recognition and p_t reconstruction. The $\mathrm{d}E/\mathrm{d}x$ measurement is used in particle identification.

The TR is emitted when a highly relativistic charged particle (*Lorentz factor* > 1000) crosses the boundary between two media with different dielectric constants. For an electron with momentum above 0.5 GeV/c, radiated photons are in the soft X-ray range 2–20 keV and travel along the particle direction. Soft X-rays are radiated with about 1% probability per boundary crossing. High efficiency is obtained with several hundred interfaces in radiators. A xenon-based gas mixture is used to absorb photons as they travel through the drift area. The produced ionization is collected by anode wires.

The TEC was being operated in the 2000/2001 RHIC experiment run with 4 planes instrumented per sector without radiator installed. A P10 gas mixture (90% argon, 10% methane) was used with gas gain of 2000–3000. Fig. 2 shows the performance of the $\mathrm{d}E/\mathrm{d}x$ measurement. Hadrons (π, K, p) are identified by the time-of-flight (ToF) with a time resolution of about 100 ps [4], and electrons by the RICH and the electromagnetic calorimeter (EMCal) [6].

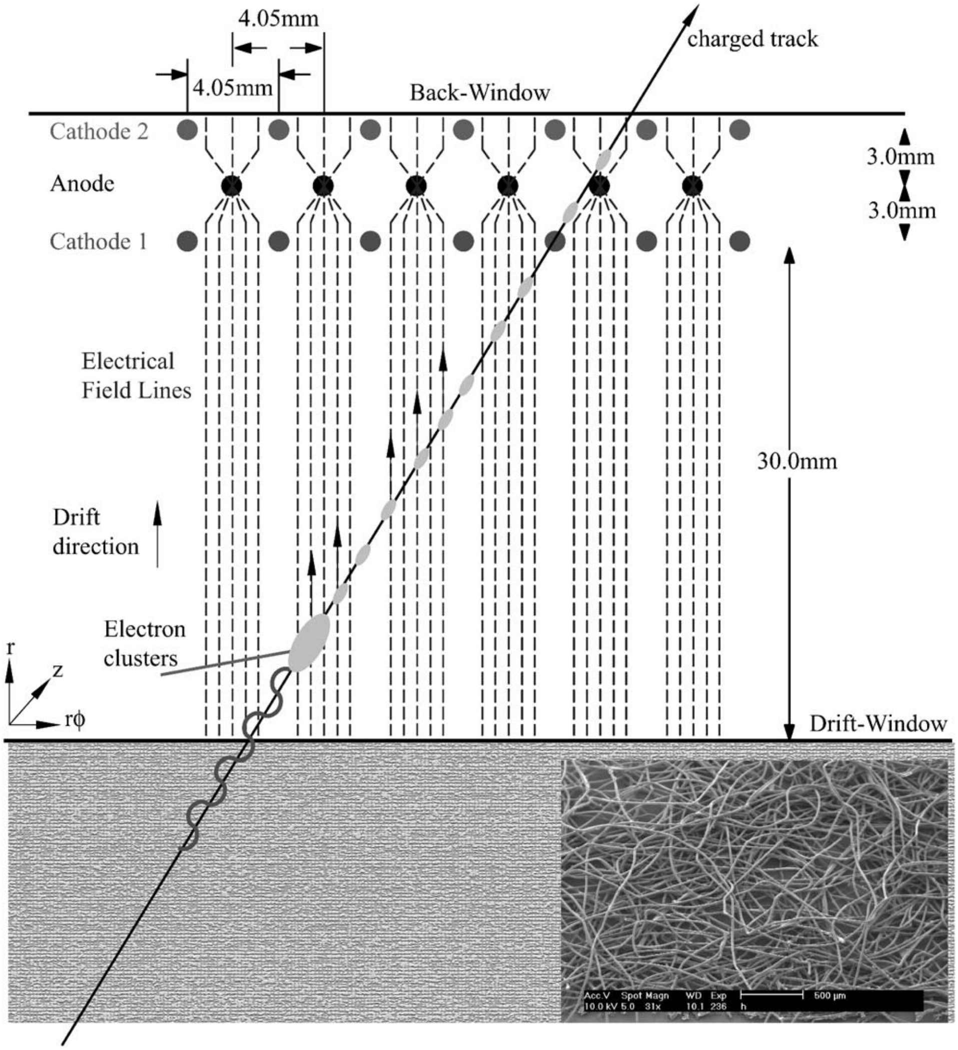

Fig. 1. Effects of a charged particle passing through the TEC, and of an electron passing through the TRD. The radiator sandwich is 6.1 cm in thickness. The scanning electron microscope picture shows 17 μm polypropylene fibers randomly oriented in the plane perpendicular to the particle direction.

4. Xenon recovery system

A gas mixture of 45%Xe + 45%He + 10%CH_4 is used to detect the sum of the ionization energy loss of charged particles in the gas and the energy deposited by X-rays. A recirculating system is designed to save the operation cost of xenon. The TEC/TRD gas system is shown schematically in Fig. 3. The gas volume of 24 chambers is 6000 l. The gas circulation rate is 12 l/min with a leakage rate of 0.12 l/min. A xenon recovery system is installed on the vent line with an exhaust rate of 0.6 l/min. The recovered xenon is redirected into the system with a makeup gas flow of 0.7 l/min.

Fig. 4 shows part of the recovery system which extracts xenon from the gas vented from chambers by using a cold trap. It has two low-temperature cryostats, each capable of accumulating 6 l liquid

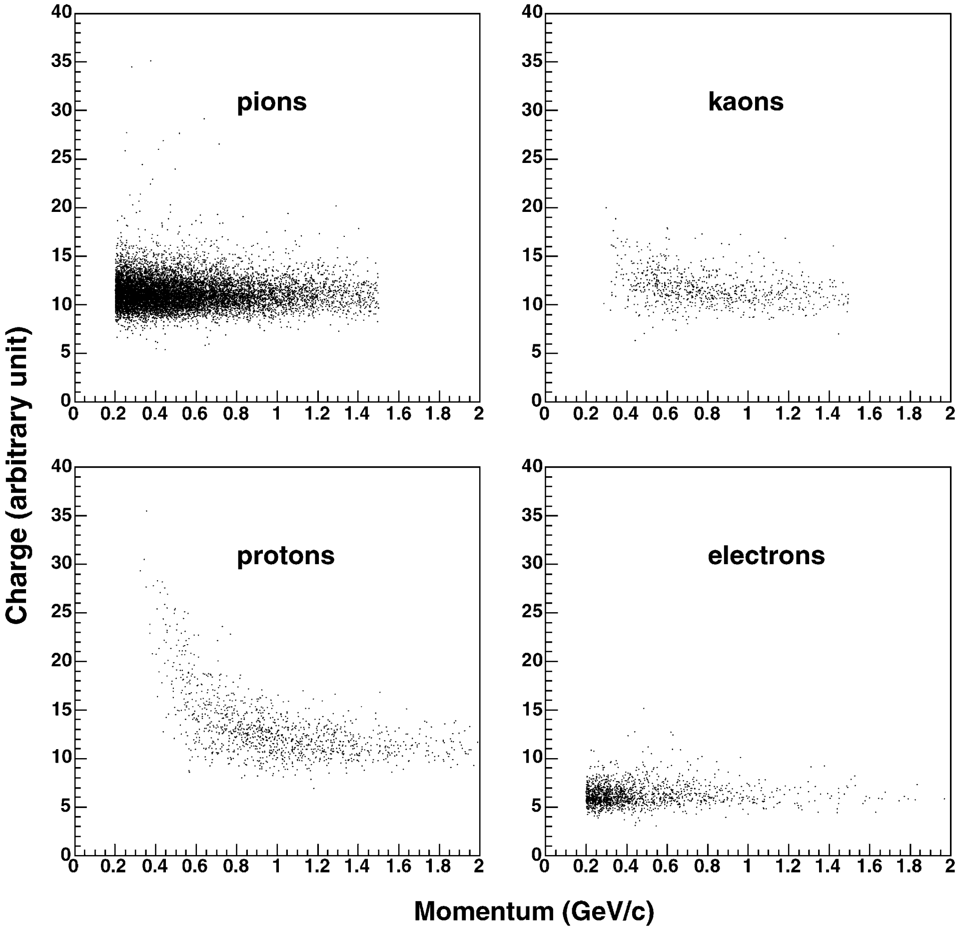

Fig. 2. The TEC dE/dx performance when 4 planes per sector are operated with a P10 gas mixture with a gas gain of 2000–3000. Hadrons (π, K, p) are identified by the ToF, and electrons by the RICH and the EMCal.

xenon. Each cryostat has an absorber on the mixture input line to remove the remaining CO_2 and H_2O. A cryostat has two stages of xenon separation—161 K with a volume of 1.3 l and 110 K with a volume of 8.6 l. In the second stage, solid xenon is collected and measured by a scale. This stage has a 100 Ω temperature transmitter connected to the gas system readout electronics to monitor the cryostat internal temperature and pressure. For normal operation only one cryostat is in running mode with the other in standby. For the TRD purging or during electrical power failure, both cryostats are employed. A coolant, liquid N_2, flows through each of the two-stage heat exchangers controlled by a temperature sensor. Two commercial 200 l Dewars (CRYOFAB CFN200-SS) with custom transfer lines are used to supply cryostats with liquid N_2. The second stage is covered with many layers of vacuum insulation to obtain a thermal insulation.

To remove xenon from the cryostats, the second stage is heated to 164 K to transform solid xenon into a liquid which is transferred to a transfer bottle placed into liquid N_2. After being disconnected from the cryogenic system, the transfer bottle is heated to the room temperature and the xenon gas is transferred into a storage cylinder for the reuse in the system.

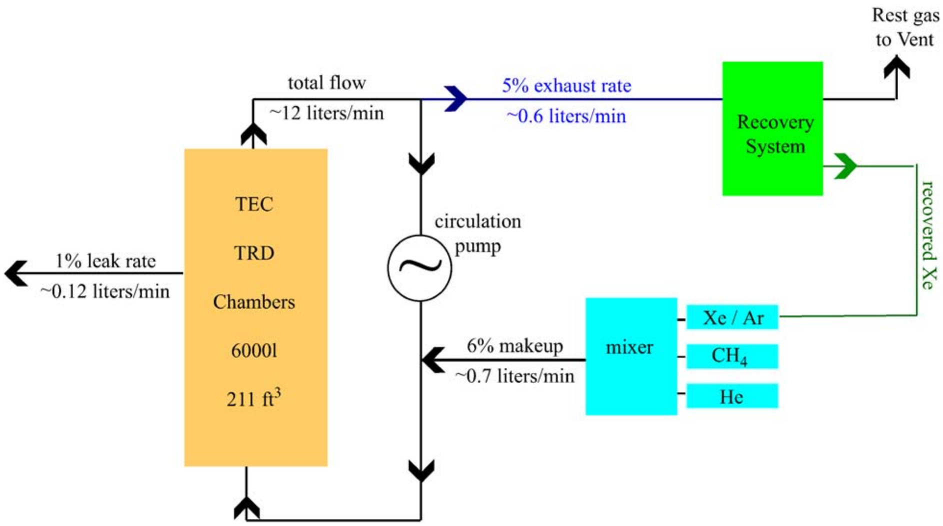

Fig. 3. The TEC/TRD gas system with the xenon recovery system installed on the vent line.

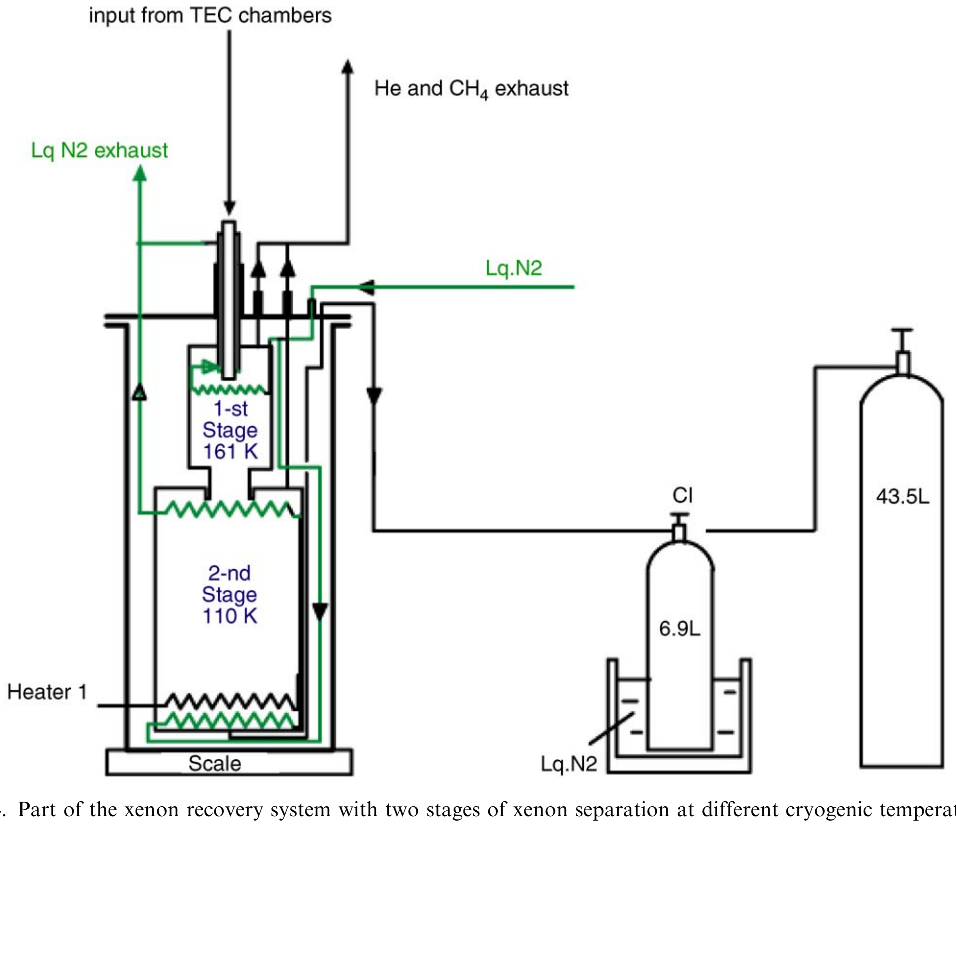

Fig. 4. Part of the xenon recovery system with two stages of xenon separation at different cryogenic temperatures.

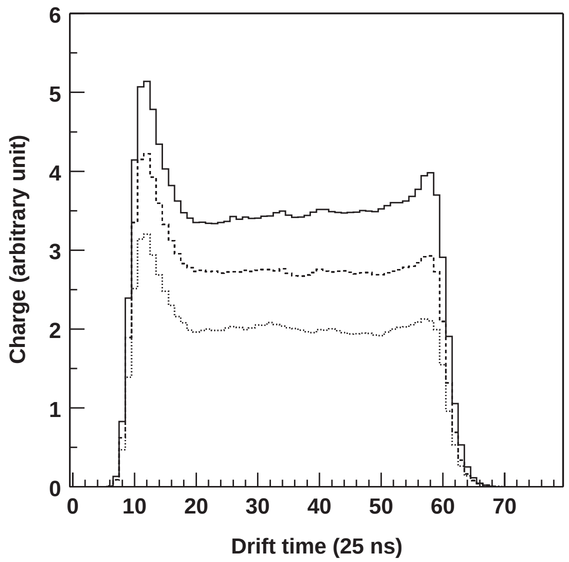

Fig. 5. Time distributions of particles with momentum of 1 GeV/c from full simulations. The dE/dx signal for pions is shown by the dotted line. The dE/dx signal for electrons is shown by the dashed line. The sum of the dE/dx and the TR signals for electrons is shown by the solid line. A gas mixture of 45%Xe + 45%He + 10%CH_4 with a gas gain 3000 is used. Many events are accumulated.

5. Prediction of the TEC/TRD simulation

The TEC/TRD will be fully operational in December 2003. Simulation of TEC/TRD operation with gas gain of 3000 is performed to evaluate the performance of particle identification. A full simulation of the TRD follows the TR formulation in Ref. [7]. Fig. 5 shows time distributions of electrons and pions at a momentum of 1 GeV/c integrated over many events. Peaks at 0.2–0.5 μs are originated from the amplification region. The energy loss of particles in the drift region causes a plateau at later times. The TR signal rises the plateau of electrons and builds up a second peak in the distribution corresponding to the entrance of the drift window. With 90% electron acceptance, a pion rejection factor, equal to 20, can be achieved with the optimal truncation level of 50%. It can be further improved by combining with the RICH and the EMCal measurements.

Acknowledgements

We would like to thank the ALICE TRD Group for fruitful discussions. This work was partly supported by the Department of Energy (USA) and Fundação de Amparo á Pesquisa do Estado de São Paolo (Brazil).

References

[1] K. Adcox, et al., Nucl. Instr. and Meth. A 499 (2003) 469.
[2] K. Adcox, et al., Nucl. Instr. and Meth. A 499 (2003) 489.
[3] E. O'Brien, et al., Nucl. Phys. A 566 (1994) 615c.
[4] M. Aizawa, et al., Nucl. Instr. and Meth. A 499 (2003) 508.
[5] K. Barish, et al., IEEE Trans. Nucl. Sci. NS-49 (2002) 1141.
[6] L. Aphecetche, et al., Nucl. Instr. and Meth. A 499 (2003) 521.
[7] M.N. Mazziotta, Comput. Phys. Commun. 132 (2000) 110.